Investigation of the Magnetospheric Boundary

Plasma and Magnetic Field Data from Explorers 33, 43, and 50

Final Technical Report

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Introduction

This is the third and final technical report on our studies of plasma and magnetic field data from Explorers 33, 43, and 50 in the vicinity of Earth's magnetopause. In general, substantial progress was made in our understanding of the plasma depletion process in the dayside magnetosheath, the nature of magnetotail boundary motion, and the geometry of the magnetospheric boundary layers.

Results from the first funding period, 10-1-75 to 9-30-76, are presented in the December 1976 technical report, and results from the second funding period, 10-1-76 to 12-31-77, are presented in the February 1978 report. Results from the final funding period, 1-1-78 to 6-30-79, are briefly summarized below and then presented in more detail in the following section.

During this third period, important progess was made in the interpretation of boundary data. Further work on the geometry of the dayside boundary layers led to a model based on the hypothesis that merging occurs only for strictly antiparallel fields. An immediate result of the hypothesis is that the predominant site of merging is removed to the vicinity of the cusps, in agreement with the conclusions of other workers. In addition, the model organizes a large body of observations and provides a qualitative solution to the problem of the half-wave rectifier response of the magnetosphere to the solar wind electric field. On the topic of magnetotail boundary motion, careful consideration of the data led to the conclusion that at lunar distance substorms are associated with

very large amplitude ($.8R_e$) compressional wave motion of the sausage mode type.

Analysis of dayside magnetosheath data continued. A study of IMF orientation for depletion and non-depletion cases suggests that depletion is most likely to occur for angles between the IMF and the normal to the magnetopause at the measurement location that are near 90^o, in agreement with predictions. Further, a study of heat flux in dayside magnetosheath plasma distributions interpreted as the signature of energized plasma ions recently discovered by Asbridge et al. (1978), suggests that these ions have their source along a given flux tube at that intersection with the bow shock where the magnetic field is most compressed, that is, in the perpendicular shock structure.

Results

The data analysis of Crooker (1977a) suggested a certain geometrical configuration of the magnetospheric boundary layers that was developed into a qualitative model (Crooker, 1977b). Further consideration of the geometry of the dayside boundary layers in light of recently published observations led to the development of dayside aspects of the model in the paper

1. Crooker, N. U., Dayside merging and cusp geometry, J. Geophys. Res., 84, 951-959, 1979.

Abstract

Geometrical considerations are presented to show that dayside magnetic merging when constrained to act only where the fields are anti-parallel results in lines of merging that converge at the polar cusps.

An important consequence of this geometry is that no accelerated flows are predicted across the dayside magnetopause. Acceleration owing to merging acts in opposition to the magnetosheath flow at the merging point and produces the variably directed, slower-than-magnetosheath flows observed in the entry layer. Another consequence of the merging geometry is that much of the time closed field lines constitute the subsolar region of the magnetopause. The manner in which the polar cap convection patterns predicted by the proposed geometry change as the interplanetary field is rotated through 360^{o} provides a unifying description of how the observed single circular vortex and the crescent-shaped double vortex patterns mutually evolve under the influence of a single operating principle.

The above paper was presented at the AGU Chapman Conference on Magnetospheric Substorms and Related Plasma Processes, Los Alamos, New Mexico, October 1978. It was well-received, and the convener of the meeting requested that the work be extended into a review for publication with the originally invited reviews. The preprint prepared for this purpose is

2. Crooker, N. U., The configuration of dayside merging, in Magnetospheric Substorms and Plasma Processes, edited by S.-I. Akasofu, Astrophysics and Space Library Series, D. Reidel, Dordrecht-Holland, in press, 1979.

Abstract

The development of the geometry of interplanetary magnetic field lines of force merging with geomagnetic field lines at the dayside magnetopause is traced from Dungey's picture of merging at the subsolar point to a three-dimensional picture in which merging occurs along curved

lines that emanate from the polar cusps. The new merging configuration is shown to be consistent with recent observations of flux transfer at the dayside magnetopause and of convection patterns at high-latitudes. In terms of a bimodal model of the magnetosphere incorporating the new merging configuration, it is estimated from observations that the contributions to convection from merging and viscous interaction are about equal. Also, a solution to the problem of the half-wave rectifier response of the magnetosphere to the interplanetary electric field is offered in terms of the new merging configuration.

Theoretical constraints on the merging process are traced from the requirement of antiparallel fields, to various dependences of the merging rate upon the angle between the merging fields, to no dependence at all. The new merging configuration assumes the antiparallel orientation. It is suggested that some instability threshold acts to prevent merging that otherwise might occur continually for all other orientations.

An invitation to present a topical paper on the same subject was extended by the conveners of the Chapman Conference on Magnetospheric Boundary Layers, Alpbach/Tyrol, Austria, June, 1979. For this purpose the application of the model to the half-wave rectifier problem was expanded into the preprint

3. Crooker, N. U., Antiparallel merging, the half-wave rectifier response of the magnetosphere, and convection, to be distributed in the proceedings of the Chapman Conference on Magnetospheric Boundary Layers, 1979.

Abstract

It has been shown that the magnetosphere responds to the north-south component B_z of the IMF in two different ways, depending upon the parameter being measured. For parameters such as polar cap electric fields and latitudinal cusp location, the response is continuous through $B_z = 0$, whereas for geomagnetic activity parameters such as ring current growth, the response is zero for northward fields and increases for increasingly southward fields, in the manner of a half-wave rectifier. This duality is interpreted in terms of two aspects of a recently proposed dayside merging configuration, in which merging occurs only for antiparallel fields along curved lines that emanate from the polar cusps. The continuous aspect is that the antiparallel merging occurs for all IMF orientations, since all orientations of geomagnetic field lines are available in the vicinity of the cusps. The half-wave rectifier aspect is that only closed dipole-like field lines merge with the IMF when it has a southward component, effecting a transfer of flux and energy to the tail lobes, whereas only open tail lobe field lines merge with the IMF when it has a northward component, effecting only a flux exchange between IMF and tail lobe field lines. In the polar cap the flux transfer for southward IMF corresponds to convection across the polar cap boundary between regions of open and closed field lines in the usual double celled pattern. The flux exchange for northward IMF corresponds to convection confined to the polar cap in a single cell.

Recent observations during times of northward IMF are consistent with the predicted single polar cap conveciton cell in addition to two cells at lower latitudes. In terms of a bimodal model of the magnetosphere,

the two additional cells are interpreted as being on closed field lines and driven by a viscous interaction. It is estimated that on the average the contributions to convection from merging and viscous interaction are comparable.

Because of the relevancy of the half-wave rectifier aspect of the model to recent observations presented at the conference, the brief treatment of the subject in paper #2 has been removed and will be combined with the above preprint #3 into a formal paper for submittal to the Journal of Geophysical Research.

The work on the magnetotail boundary motion outlined in the February, 1978, technical report has been synthesized into the reprint

4. Crooker, N. U., and G. L. Siscoe, Large-amplitude substorm motion of the magnetotail boundary, Geophys. Res. Lett., 6, 105-108, 1979.

Abstract

During a period of several days when the solar wind was relatively quiet, the magnetotail boundary near lunar distance swept back and forth past Explorer 33 as the spacecraft traveled through a distance perpendicular to the Earth-sun line of about 17 R_e. The boundary crossings are remarkably well-correlated with peaks in the AE index, even though the magnitudes of the peaks are only on the order of 200 nT. Examination of the regions of multiple crossings on other Explorer 33 and 35 orbits reveals that they commonly cover large distances perpendicular to the Earth-sun line, although correlation with AE is often obscured, probably by external solar wind conditions. We conclude that a substantial fraction of the scatter in published statistical plots of boundary crossing positions can be accounted

for in terms of an internal substorm-related motion with an amplitude of 5-8 R_e. The data suggest that the motion takes the form of a compressional deformation wave convecting down the tail.

This paper was also presented at the AGU Fall Annual Meeting, San Francisco, December, 1978.

Recently published is the paper from the preprint presented in the February 1978 technical report

5. Crooker, N. U., T. E. Eastman, and G. S. Stiles, Observations of plasma depletion in the magnetosheath at the dayside magnetopause, J. Geophys. Res., 84, 869-874, 1979.

Abstract

In a set of 17 low- to mid-latitude crossings of the dayside and near-dayside magnetopause, Imp 6 plasma measurements show 11 cases of decreases in magnetosheath density just outside the boundary which are consistent with plasma depletion owing to magnetic flux tube compression as the field becomes draped against the magnetopause. Pressure anisotropies in the sense $p_\perp > p_\parallel$ are a predicted result of the plasma depletion and field compression, and such anisotropies are observed. Application of the mirror instability criterion, which predicts growth of slow mode magnetoacoustic waves for values of $p_\perp / p_\parallel$ greater than a critical value, suggests that dayside magnetosheath plasma is usually unstable. One of the seventeen cases shows long-period waveforms in the 100-s density data that are 180^o out of phase with simultaneous waveforms in the magnetic field strength. We interpret these data as the signature of slow mode magnetoacoustic waves.

In addition to the above published work on depletion, a search was made for some magnetic field parameter that correlated with whether or not depletion was observed on a particular magnetopause crossing. Hourly averages of IMF orientation from King (1977) were available for 11 depletion and 10 non-depletion cases. Since depletion is predicted to occur for large field compression, and compression across the dayside is maximum when the IMF is perpendicular to the sun-Earth line and minimum when it's parallel, this angle was tested for correlation, but none was found. When the magnetic field drapes against the magnetopause, its major components are in the y and z directions, and in this plane compression is greatest along a given field line at the point that passes nearest to the subsolar point.

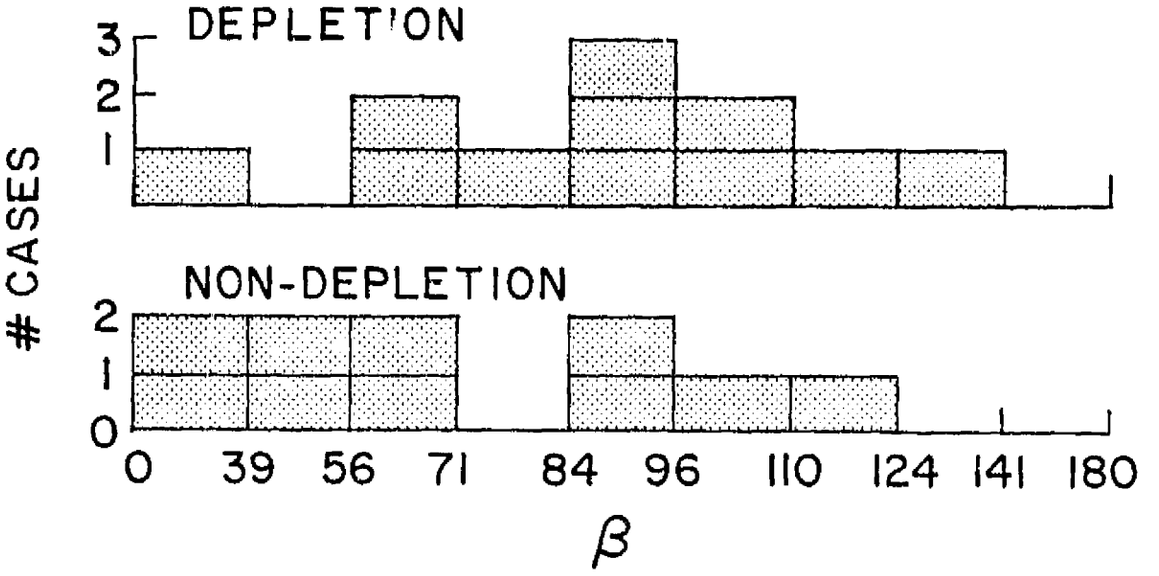

Figure 1

The spacecraft distance from this point was tested with use of the measured magnetosheath field orientation, but again no correlation was found. Nor was any correlation found with the angle between the field at the spacecraft and the subsular direction. The field parameter that does give a good suggestion of a correlation is the angle β between the IMF and the boundary normal at the magnetopause crossing. If $\beta \approx 0^{o}$, local compression is expected to be small. Histograms of β are shown in Fig. 1, separately for the depletion and non-depletion cases. The abscissa is divided into bins of equal solid angle. Although there are not enough cases to draw firm conclusions, there is certainly a suggestion that the distributions are different for depletion and non-depletion, and the difference is in the predicted sense. This study may be extended to include a statistically significant number of cases with the ISEE data analysis presently being funded by a separate grant.

A final study of the Explorer 43 dayside magnetosheath is outlined below in a preliminary abstract of the paper

6. Crooker, N. U., G. L. Siscoe, T. E. Eastman, and G. S. Stiles, On the source of energetic plasma ions in the magnetosheath, preprint in preparation, 1979.

Abstract

Magnetic field and plasma measurements from Explorer 43 in the dayside magnetosheath often reveal plasma distributions with marked skewness or heat flux along the magnetic field in the higher energy ranges. We identify this heat flux as a signature of the energetic (>3 keV) plasma ions discovered by Asbridge et al. (1978).

Twenty-five cases were analyzed with the aid of the magnetic field draping models of Alksne (1967). The results indicate that the heat flux may be directed either toward the downstream or the upstream intersection of the field line with the bow shock, or it may be completely absent. We suggest that the heat flux is caused by greater energization of ions at that intersection where greater field compression occurs. A simple model shows that a delicate balance can exist between compressions behind the bow shock at either end of a field line as it passes through the magnetosheath, consistent with either the absence or presence of observable heat and flux and with either upstream or downstream heat flow. Since in the parallel shock region there is usually more compression at the downstream intersection of the field line with shock, the resulting energized ions would be directed upstream and may pass through the parallel shock region, forming the diffuse upstream ion population, consistent with the geometry proposed by Greenstadt et al. (1979).

An example of a distribution showing marked skewness is given in Fig. 2. The contours of constant phase space density in the lower half of the figure were smoothed by eye from measurements averaged over 8 min. The V_x and V_y axes are the ecliptic coordinates in the spacecraft frame of reference, and the short heavy arrow pointing from the origin indicates the direction and magnitude (200 km/sec) of the bulk flow in that plane.

For this particular case the magnetic field lay in the ecliptic plane, and the ecliptic component of the bulk flow was field-aligned. The skewness in the distribution along the field is apparent especially in the contours that are fourth and fifth from the center.

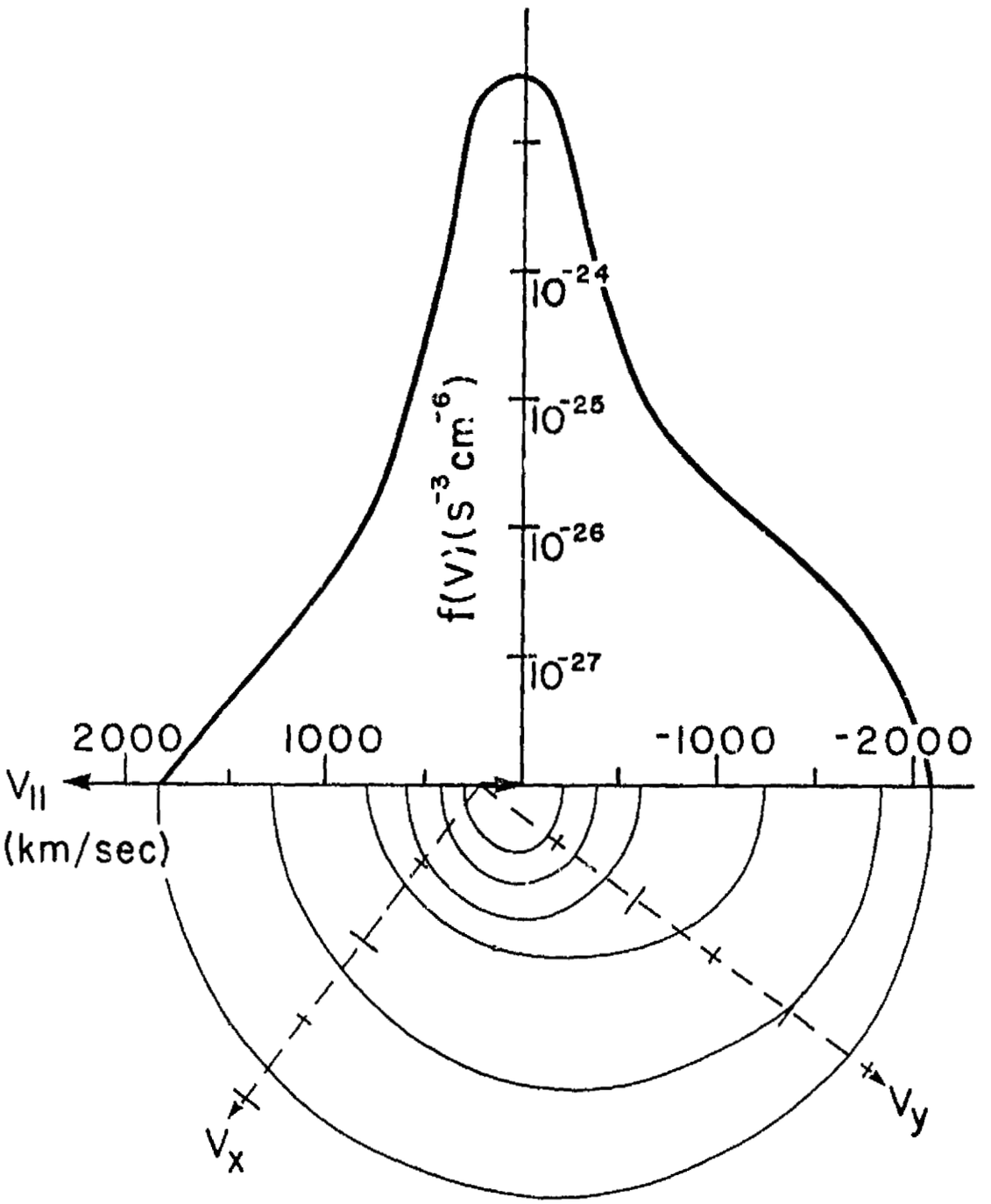
10^{-24}
10^{-25}
10^{-26}
10^{-27}
$f(V_i)(S^{-3}cm^{-6})$
2000
1000
-1000
-2000
$V_{||}$
(km/sec)
V_x
V_y

Figure 2

They intersect the minus $V_{||}$ axis at values that are about 50% greater in magnitude than the values at their intersections with the plus $V_{||}$ axis. The upper half of Fig. 2 shows an elevation view of the contours; it is a cross-section of the distribution along the $V_{||}$ axis showing the magnitude of the phase space density. The shoulder on the right is prominant in the energy range > 3 keV (~750 km/sec), which is the range of the energetic ions detected by Asbridge et al. (1978).

Completion of the above study was delayed because of apparent offsets discovered in the locations of the centers of the distributions. An attempt was made to correct these offsets by hand. If this procedure is successful, a preprint will be completed soon. If not, the analysis will be carried over to the ISEE data, where the same patterns have been detected.

References

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